

## Nuclear Science Division Newsletter

2013/3

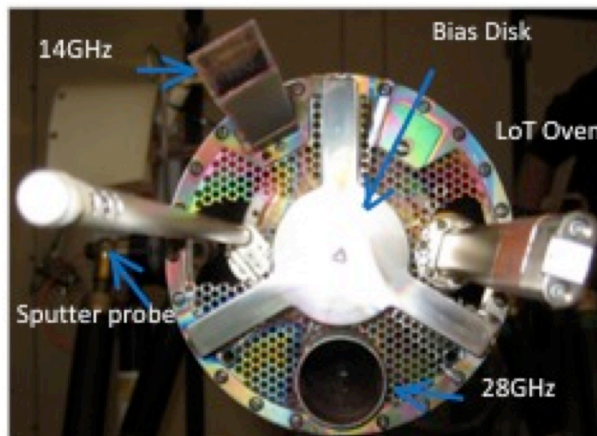
- **VENUS produces record high-intensity beams for SHE experiments** page 1
- **Production and study of element 115 and its daughter decays** page 2
- **Quarks, nuclei, and the early universe** page 3
- **Installation of DCal means no more escape for particle jets in ALICE** page 4
- **NSD Fragments** page 5

### VENUS produces record high-intensity beams for superheavy element experiments

Production cross-sections for superheavy elements are extremely low, atoms/day to atoms/month, and experiments require very high beam currents of  $\sim 10^{13}$  ions/s and highly selective and efficient separators.

The superconducting ECR ion source, VENUS, recently completed a long run supplying high-intensity  $^{48}\text{Ca}$  beams, which were accelerated to 262 MeV by the 88-Inch Cyclotron for a heavy-element experiment. The beams were delivered to a  $^{243}\text{Am}$  target to study the properties of element 115 (see subsequent article). The maximum  $^{48}\text{Ca}^{11+}$  beam extracted from the cyclotron during the experiment was 2 particle  $\mu\text{A}$ , corresponding to an electrical current of 22 e $\mu\text{A}$ . This is more than twice the maximum  $^{48}\text{Ca}$  current previously achieved with the 88-Inch Cyclotron. For most of the experiment, the beam intensity was limited to 1  $\mu\text{A}$  to minimize beam damage to the Americium target. A rough estimate of the integrated beam gives a total of  $2.7 \times 10^{19}$   $^{48}\text{Ca}$  particles delivered, or about 2.1 mg over the length of the run.

Two factors made the performance of the ECR/cyclotron system significantly better than previous operation with the rare and costly  $^{48}\text{Ca}$  isotope. First the improved low-temperature oven, shown below, used to produce the calcium atomic beam coupled to the large-volume VENUS source resulted in an ionization efficiency (atoms into the plasma to atoms extracted) of 4.9% for the  $\text{Ca}^{11+}$ , which is a significant improvement over the ionization efficiency of the AECR-U. This efficiency was achieved at an extracted beam intensity of VENUS of 75 e $\mu\text{A}$ , which was sufficient to produce the needed beam intensity from the cyclotron. Second, a spiral inflector developed as part of the High Voltage Upgrade ARRA project was used to deflect the beam into the center region of the cyclotron. The spiral has no grid and operated without repair for the entire length of the run. It also allows higher injection and capture efficiency because it can be used with a high injection voltage, which was 27 kV in this case.

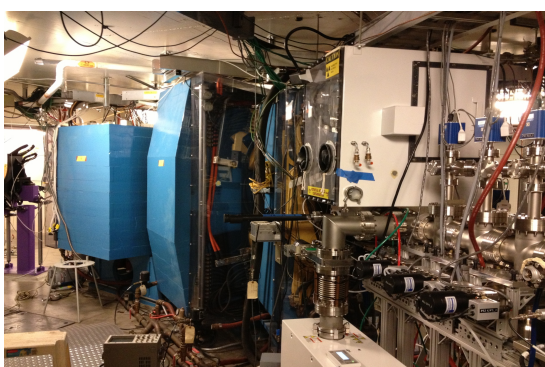


*End view of the VENUS injection system showing the low-temperature oven used to produce the  $^{48}\text{Ca}$  vapor.*

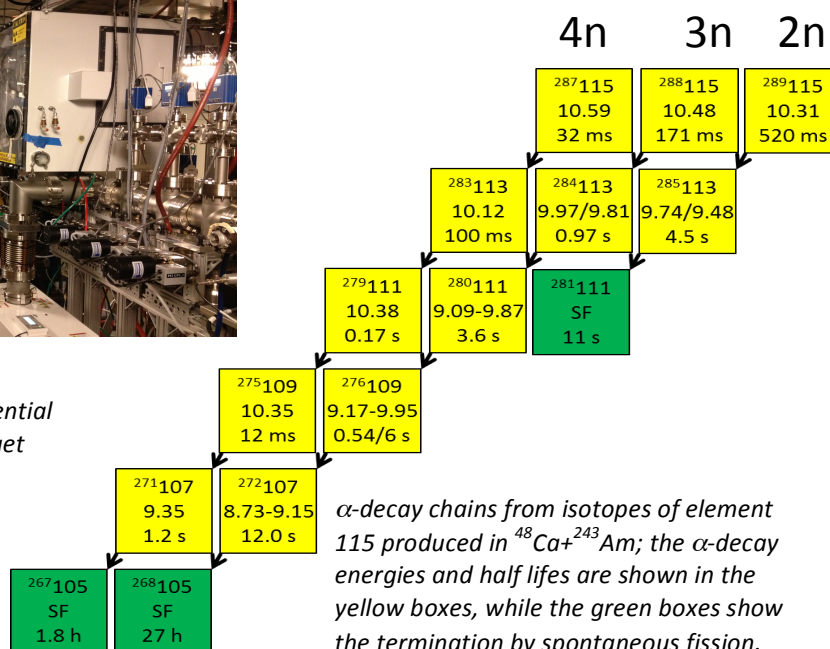
## Production and study of element 115 and its daughter decays

Over the past 15 years seven new elements with proton numbers  $Z=112-118$  have been reported and much progress has been made to answer whether an island of relative stability exists for superheavy nuclei beyond uranium (92 protons). However, little is known about these nuclei other than they can be created in the lab. Measurements carried out at GSI in Germany and at the LBNL 88-Inch Cyclotron have begun to find more detailed structural information on these superheavy nuclei and provide a direct determination of their atomic number by measuring characteristic X-ray decays.

The LBNL experiment was done at the 88-Inch Cyclotron between April and June 2013 using the new high-intensity  $^{48}\text{Ca}$  beam produced by the VENUS ion source (see preceding article) to irradiate targets of  $^{243}\text{Am}$ . Atoms of element 115 were separated from the beam and unwanted reaction products in the Berkeley Gas-filled Separator (BGS) and implanted into the new corner cube clover (C3) detector featured in the August 2012 NSD Newsletter. During 38 days of irradiation, a record of 43 decays of element 115 were produced and observed at the BGS. In total, combined with the data taken at GSI (November-December 2012), over 70 decay chains of element 115 were observed making it possible to correlate the decay of this element and its daughters ( $Z=113, 111, 109, 107$ ) with observed  $\gamma$ -ray decays. Multiple photons and potential X-rays were observed with the decay of element 115 and its daughters. While these data did not enable a firm determination of the atomic number, the first spectroscopic data on the structure of superheavy elements was obtained and compared to nuclear structure models. Results from the GSI-based subset of the data were reported by D. Rudolf et al. in Phys. Rev. Lett.



The BGS "windowless" differential pumping system and the target box (right) followed by the large acceptance dipole magnets (blue).



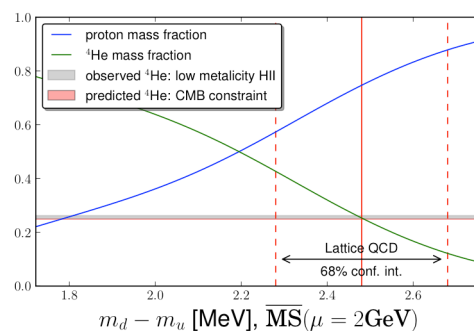
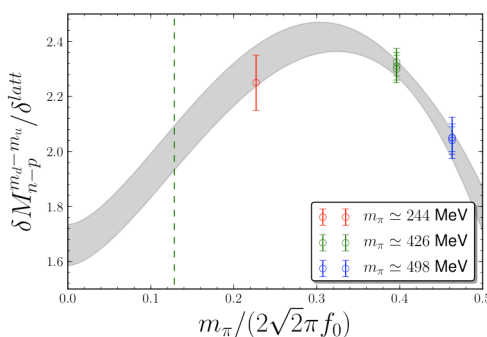
$\alpha$ -decay chains from isotopes of element 115 produced in  $^{48}\text{Ca}+^{243}\text{Am}$ ; the  $\alpha$ -decay energies and half lives are shown in the yellow boxes, while the green boxes show the termination by spontaneous fission.

## Quarks, nuclei, and the early universe

Quantum ChromoDynamics (QCD) is the fundamental theory of the nuclear strong force, the interaction between quarks and gluons. At low energies, the coupled non-linear interactions are non-perturbative, binding the quarks and gluons into hadrons. QCD can be solved numerically on supercomputers with the lattice QCD technique. Algorithmic and hardware developments have recently allowed more realistic calculations of simple QCD observables with nearly physical quark masses. Computing properties of light nuclei is significantly more challenging but preliminary calculations are now available. This makes it possible, for the first time, to make quantitative connections between the quarks and the formation of light nuclei in the early universe by elucidating the dependence of the nuclear observables on fundamental parameters, such as the electromagnetic coupling and the quark masses.

Big Bang Nucleosynthesis (BBN) is the theory that describes the production of light nuclear elements (deuterium,  $^3\text{He}$ ,  $^4\text{He}$ ,  $^7\text{Li}$ , ...) in the primordial universe, from roughly 1s to 15m after the Big Bang. With the nuclear reactions measured experimentally and the primordial baryon-to-photon ratio determined from the Cosmic Microwave Background,  $\eta \sim 10^{-9}$ , BBN provides a parameter-free prediction of the abundances of the light nuclei, in good agreement with observations. Lattice QCD can provide the dependence of the inputs to BBN as functions of the quark masses  $m_d$  and  $m_u$ . For example, BBN depends most sensitively upon the neutron-proton mass splitting, which can be computed as a function of the pion mass and  $m_d - m_u$ . A preliminary calculation of these dependences [1] (left figure) allows a determination of the  $^4\text{He}$  abundance in universes having different values of  $m_d - m_u$  [2]. Alternatively, tighter constraints can be placed upon the quark mass splitting [3] (right figure). These results can be combined with knowledge of the electromagnetic contribution to neutron-proton mass difference [4] to place improved constraints on a possible time variation of the fundamental constants.

In the near future, lattice QCD calculations of the nuclear binding energies and reaction rates as functions of the fundamental parameters of the Standard Model will also be possible, enriching our understanding of the universe and quantitatively connecting the quarks with the cosmos.



[1] A. Walker-Loud *et al.*, in preparation.

[2] P. Banerjee, W. Haxton, T. Luu, and A. Walker-Loud, in preparation.

[3] G. Colangelo *et al.*, Eur. Phys. J. C71, 1695 (2011).

[4] A. Walker-Loud, C.E. Carlson, and G.A. Miller, Phys. Rev. Lett. 108, 232301 (2012).

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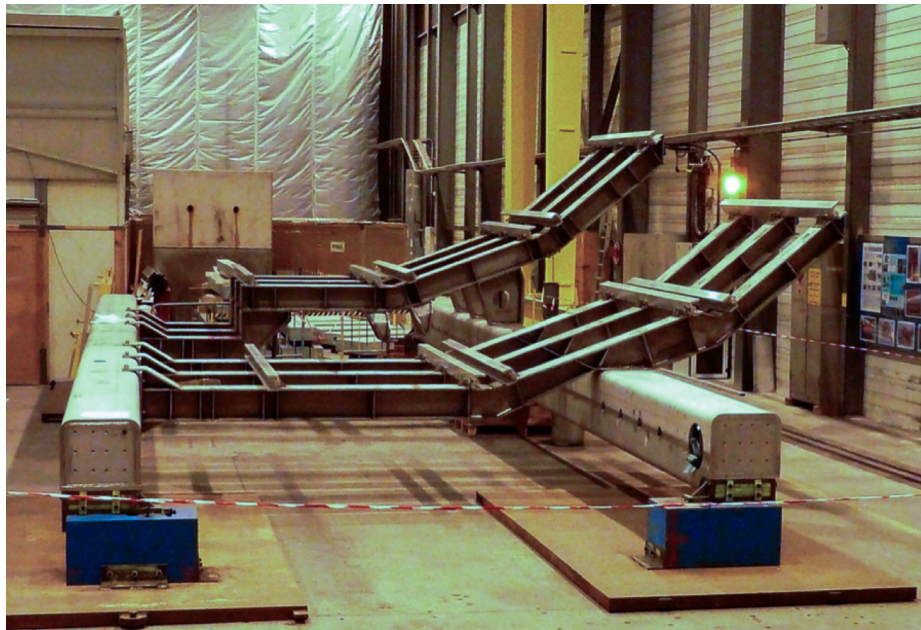
### Installation of DCal means no more escape for particle jets in ALICE

The ALICE detector at the CERN LHC is currently being augmented with a new calorimeter arm, DCal, designed to extend significantly its capabilities to detect and measure jets of particles. DCal is a large lead-scintillator detector with photo-diode readout placed in azimuthally opposite of the existing electromagnetic calorimeter (EMCal). This is the optimal configuration for measuring back-to-back jets originating in the interactions of quarks and gluons in ultra-high-energy collisions of heavy nuclei.

The DCal has been built by the same international team that built the EMCal, led by US institutions with participation from France, Italy, Japan and China. LBNL is the Lead Laboratory for the US project, with strong contributions from both the LBNL Nuclear Science and Engineering Divisions. The DCal uses the same type of detectors as the EMCal and will be operated in conjunction with the PHOS detector, another existing lead-tungstate calorimeter with smaller acceptance but very high precision,

The new DCal/PHOS/EMCal configuration will allow ALICE to perform new measurements. For example, the photon-jet coincidences will be measured with high precision and provide additional precise probes of the quark-gluon plasma. The DCal/EMCal will also measure the correlation of fully reconstructed jet pairs, allowing the study of the energy balance between recoiling jet pairs, another tool for probing jet quenching. The new back-to-back jet data for  $pp$  collisions will provide important control measurements and improve the understanding of the energy resolution of and the energy scale of its jet measurements.

The installation of the new DCal is proceeding on schedule. The detector will be completed in autumn 2014, well in time for commissioning of the LHC at top energy and luminosity.



*The new support beams and support cradle for DCal and PHOS have been assembled and are ready for installation.*



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## NSD Fragments

### The 12<sup>th</sup> Exotic Beam Summer School held in Berkeley

The 2013 Exotic Beam Summer School (EBSS) was hosted by the NSD July 28<sup>th</sup> to August 4<sup>th</sup>. Rod Clark, the LBNL representative on the EBSS Board of Directors, was the local organizer. The EBSS is jointly organized by ANL, LBNL, LLNL, MSU, and ORNL for the purpose of preparing the young generation for the opportunities presented by the Facility for Rare Isotope Beams being constructed at MSU, along with other existing and planned exotic beam facilities around the world, and it focuses on the science of exotic nuclei, including nuclear structure, nuclear astrophysics, and fundamental interactions, as well as the application of nuclear science and technology in the modern world.

The school has a unique format: The mornings were devoted to lectures, taking place at the UCB Foothill Complex where the students were staying, while the afternoons offered hands-on activities on ECR ion sources, digital techniques for  $\gamma$ -ray spectroscopy, Coulomb excitation and nuclear collectivity, scintillator detectors, decay detection techniques for super-heavy nuclei, and theory of pairing in nuclei. Divided into smaller groups, the students had good opportunity for interacting closely with the scientists leading the activities; the hands-on activities are always the highlight for the EBSS students.

As has happened every year, many more students applied for the school than could be accommodated, a good sign for the vitality of the field. In total 42 were accepted from institutions in the US and abroad.



**Dhevan Gangadharan** and **Mustafa Mustafa** have joined the RNC Program as postdocs; Dhevan will be based at CERN to work with Constantin Loizides, while Mustafa will be working with Jim Thomas at BNL.

**André Walker-Loud**, nuclear theorist at LBNL 2010-2013, has recently become an Assistant Professor at the College of William and Mary with a joint appointment at JLAB; he received the 2013 Ken Wilson Award for excellence in lattice field theory; he remains affiliated with LBNL as an active collaborator.

*The NSD Newsletter is edited by Jørgen Randrup (JRandrup@LBL.gov) and issues are archived on the NSD home page: <https://commons.lbl.gov/display/NSD/home/>*